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TREE DIMENSIONS AND THEIR EFFECTIVENESS AS BIOMASS PREDICTORS

by

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Introduction

Researchers have been using tree dimensions to estimate total tree and tree component biomass for almost 200 years. In 1788, Thomas Jefferson asked Thomas Paine for a procedure to estimate the amount of wood in a tree (Fonar 1969). After examining the problem Paine suggested that the mathematical relationship used to estimate the flow of water in a fountain could be used to estimate the wood in the stem and branches of a tree. Paine said the amount of wood in a tree was related to the square of the diameter at the bottom, at any point up the tree, and the height of the tree. Since this early beginning researchers have used a variety of tree dimensions as predictors of tree biomass. Comprehensive reviews of the biomass literature (Keays 1971, Stanek and State 1978, Madgwick 1976, Art and Marks 1971, Young 1976, and Hitchcock and McDonnell 1979) illustrate the wide diversity of tree dimensions used to estimate tree biomass.

In this paper I discuss the commonly measured tree dimensions and their effectiveness as biomass predictors. I also suggest tree dimensions that federal researchers should use as standard independent variables when developing biomass equations for publication.

Discussion

Diameter at breast height squared $(d.b.h.)^2$ is the tree dimension most highly correlated with above-stump total tree weight (Table 1). The second most highly correlated single tree dimension is diameter at the base of the live full crown squared $(DBC)^2$. Total tree height (TH) and height to 4-inch d.o.b. top (H4) are both equally well correlated with total tree weight. Other variables such as height to base of crown, crown length, crown ratio, and crown class are not consistently well correlated with total tree weight.

The best predictor of stem weight to a 4-inch top is d.b.h. squared (Table 2). Next to $(d.b.h.)^2$, the dimension most closely correlated with stem weight is d.o.b. at base of live full crown squared. Height to a 4-inch d.o.b. top is more highly correlated with stem weight than is total height. However, TH or H4 in combination with $(d.b.h.)^2$ are equally well correlated with stem weight. Stem taper expressed as form class or form quotient is sometimes useful as a third variable with d.b.h. and height to improve stem weight predictions (Hughes 1978).

Crown weight is more variable and difficult to estimate than total tree or stem weight. Researchers have examined the relationship of crown weight to

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Table 1. Linear association between total tree weight[1/] and various tree dimensions for several southern species.

Species[2/]	Tree dimension									
	$(d.b.h.)^2$	Total height	Ht. to 4-in. top	$(d.b.h.)^2$ x (TH)	$(d.b.h.)^2$ (H4)	$(DBC)^2$ [3/]	Ht. to crown base	Crown length	Crown ratio	Form class
	Correlation coefficient (r)									
Loblolly pine	.99	.77	.88	.99	.99	.96				.59
Yellow-poplar	.99	.83	.81	.98	.98	.94	.59	.67	.01	.31
Sweetgum	.96	.83	.80	.96	.95	.96	-.09	.86	.54	.48
N. Red oak	.97	60	.71	.97	.97	.94	-.07	.65	.34	.07
N. Red oak	.98	.85	.90	.98	.98	.90	.48	.64	.14	.28
S. Red oak	.99	.81	.83	.99	.99	.96	.04	.81	.55	.56
Scarlet oak	.99	.89	.91	.99	.99	.95	.38	.84	.53	.18
White oak	.98	.82	.80	.98	.98	.97	.35	.81	.14	.71

[1/] Weight of wood and bark.

[2/] See Table 2 for number and size of trees sampled.

[3/] D.o.b. at base of live full crown.

Table 2. Linear association between stem weight[1/] and various tree dimensions for several southern species.

Species	Trees sampled	d.b.h. range	Tree dimension							
			$(d.b.h.)^2$	Total height	Ht. to 4-inch d.o.b. top	$(d.b.h.)^2$ x (TH)	$(d.b.h.)^2$ x (H4)	$(DBC)^2$ [2/]	Ht. to crown base	Form class
	(No.)	(In.)	---------- Correlation coefficient (r) ----------							
Loblolly pine	40	3.8-12.5	.99	.80	.90	.99	.99	.93		.58
Yellow-poplar	26	5.5-20.3	.99	.88	.90	.99	.99	.95	.65	.32
Sweetgum	24	5.7-20.7	.98	.87	.86	.99	.99	.93	-.03	.48
N. Red oak	35	11.7-24.7	.96	.68	.79	.99	.99	.91	.06	.03
N. Red oak	36	5.9-11.3	.98	.85	.90	.99	.99	.88	.52	.30
S. Red oak	29	5.4-22.0	.99	.84	.86	.99	.99	.95	.10	.60
Scarlet oak	28	5.1-20.0	.99	.91	.93	.99	.99	.96	.41	.19
White oak	23	5.6-20.9	.98	.88	.85	.99	.99	.93	.44	.72

1/ Weight of wood and bark.

2/ D.o.b. at base of live full crown.

TH, H4, $(d.b.h.)^2$, $(DBC)^2$, height to base of full crown, crown length, crown width, crown ratio, and crown class. Most researchers have found $(DBC)^2$ to be the best single predictor of crown weight in both conifers (Storey et al. 1955, Brown 1976, Ralston 1973) and hardwoods (Storey and Pong 1957, Phillips and Cost 1979). Research conducted in the southeastern United States agrees with these findings (Table 3). However, $(DBC)^2$ has limited application because it is not easily measured accurately on standing trees (Crow 1971, Loomis et al. 1966).

The dimension with the second highest correlation with crown weight is $(d.b.h.)^2$ as illustrated in Table 3. Brown (1971) also found $(d.b.h.)^2$ alone to be highly correlated with crown weight for 11 conifer species, and that the addition of total height, crown class and especially crown ratio improved his crown predictions. In shortleaf pine, crown weight estimates determined from $(d.b.h.)^2$ and crown ratio combined were almost as accurate as those using $(DBC)^2$ alone (Loomis et al. 1966). Weight of foliage alone and branchwood and bark weight are highly correlated with $(d.b.h.)^2$ x (TH) (Clark and Taras 1976).

Limited work has been done on estimating the weight of stumps and roots because of the difficulty and expense of extracting them. Since equipment for harvesting stumps and taproots is commercially available (Koch and Coughran 1975), accurate weight equations are needed. Stump height, d.b.h., d.o.b. at stump height, d.o.b. at ground-line, H4, and TH are some of the measurements that have been examined for estimating stump and root weight.

The linear associations between loblolly pine stump and taproot weight and various tree dimensions are shown below:

	Tree dimension						
Components	$(d.b.h.)^2$	d.o.b. ground-line	Total height	Height to 4-inch top	$(DBC)^2$	Form class	$(d.b.h.)^2$ (TH)
	Correlation coefficient (r)						
Stump and tap-root weight	.93	.90	.74	.85	.90	.76	.94

The dimension most highly correlated with stump and taproot weight was $(d.b.h.)^2$. Diameter outside bark at ground-line was the second best variable. Ralston (1973) also reported $(d.b.h.)^2$ to be highly correlated with stump and root weight and found only slight improvement when diameter at stump height was used. Johnstone (1971) found that $(d.b.h.)^2$ and TH were highly correlated with stump and root weight in lodgepole pine.

The square of (d.b.h.) alone or in combination with height is the best predictor of total tree and tree component weight (Tables 1, 2, 3). Since height and d.b.h. are closely correlated in individual even-aged stands, $(d.b.h.)^2$ alone can be used to develop local weight equations (Madgwick 1971, Wiant et al. 1977). However, equations developed for wide geographic application require both $(d.b.h.)^2$ and height as independent variables to predict tree weight accurately (Crow 1978, and Honer 1971). To illustrate this, I developed total

Table 3. Linear association between crown weight[1/] and various tree dimensions for several southern species.

Species[2/]	Tree dimension									
	$(d.b.h.)^2$	Total height	Ht. to 4-in. top	$(d.b.h.)^2$ x (TH)	$(d.b.h.)^2$ x (H4)	$(DBC)^2$ [3/]	Ht. to crown base	Crown length	Crown ratio	Crown class
	Correlation coefficient (r)									
Loblolly pine	.86	.58	.68	.85	.84	.87				
Yellow-poplar	.82	.54	.53	.79	.78	.81	.33	.50	.10	-.59
Sweetgum	.75	.60	.54	.75	.72	.91	-.35	.82	.66	-.44
N. Red oak	.88	.40	.50	.85	.84	.92	-.29	.71	.51	-.80
N. Red oak	.90	.77	.79	.90	.88	.93	.31	.71	.29	-.67
S. Red oak	.96	.72	.75	.96	.96	.96	.06	.79	.58	-.74
Scarlet oak	.97	.83	.85	.97	.96	.97	.30	.82	.55	-.68
White oak	.92	.68	.67	.90	.89	.96	.18	.75	.24	-.34

[1/] Weight of wood and bark.

[2/] See Table 2 for number and size of trees sampled.

[3/] D.o.b. at base of live full crown.

tree white oak equations based on $(d.b.h.)^2$ alone and $(d.b.h.)^2$ and total height for three locations with widely different height to d.b.h. ratios. Each equation was applied to the same set of tree dimensions and plotted over d.b.h. Figure 1 shows the difference in estimated total tree weight that would occur when the $(d.b.h.)^2$ equation from one location is applied to another location. Figure 2 shows how these differences in estimated weight can be reduced when $(d.b.h.)^2$ and total height are used as the independent variables.

The square of d.b.h. and some measure of height are obviously the dimensions that should be used as independent variables in weight equations. Total height and height to 4-inch top are equally well correlated with total tree and component weight when used in combination with $(d.b.h.)^2$ but total height should be the standard height for biomass equation development (Tables 1, 2, 3). Total height is a fixed point on all size trees whereas, height to 4-inch top occurs only in larger trees.

Total height and d.b.h., however, will not meet the needs of all forestry groups. The most valuable portion of the tree—the saw-log merchantable stem, is commonly cruised by d.b.h. and saw-log merchantable height (MH) in hardwoods. Pulpwood trees are commonly tallied by d.b.h. and height to a 4-inch d.o.b. top. Therefore, the forest industry needs biomass equations based on these tree dimensions. The square of d.b.h. and saw-log merchantable height are more highly or as highly correlated with the saw-log stem weight than $(d.b.h.)^2$ and total height or $(d.b.h.)^2$ and height to 4-inch top (Table 4). The square of d.b.h. and saw-log height are also highly correlated with stem and total tree weight and have been found to be good predictors of hardwood total tree and tree component weights, (Clark _et al_. 1980a, 1980b, 1980). The same tree dimensions should be used as independent variables to estimate all components of the tree to ensure component additivity (Kozak 1970).

Summary

Diameter at breast height and total tree height are the tree dimensions that should be used as standards for development of total tree and tree component biomass equations. Federal researchers should also publish biomass equations based on $(d.b.h.)^2$ alone, and $(d.b.h.)^2$ in combination with height to saw-log top and height to 4-inch top to meet the needs of the forestry industry. Diameter at base of live crown should be measured on all trees sampled for biomass equation development and used as an independent variable when more accurate crown estimates are needed.

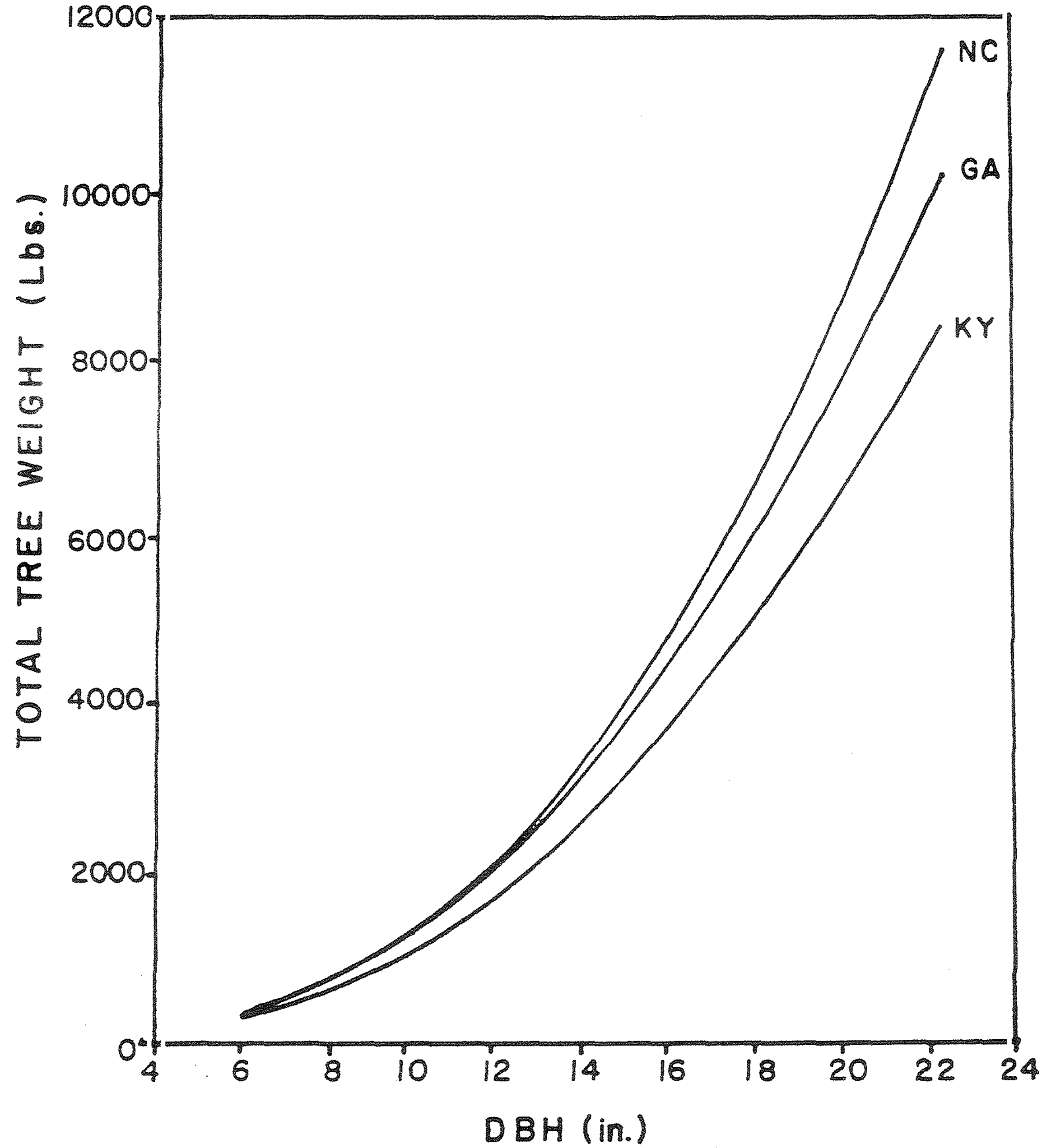

Figure 1. Predicted white oak total tree weight when equations, based on d.b.h. for locations with different total height to d.b.h. ratios, are applied to the same trees.

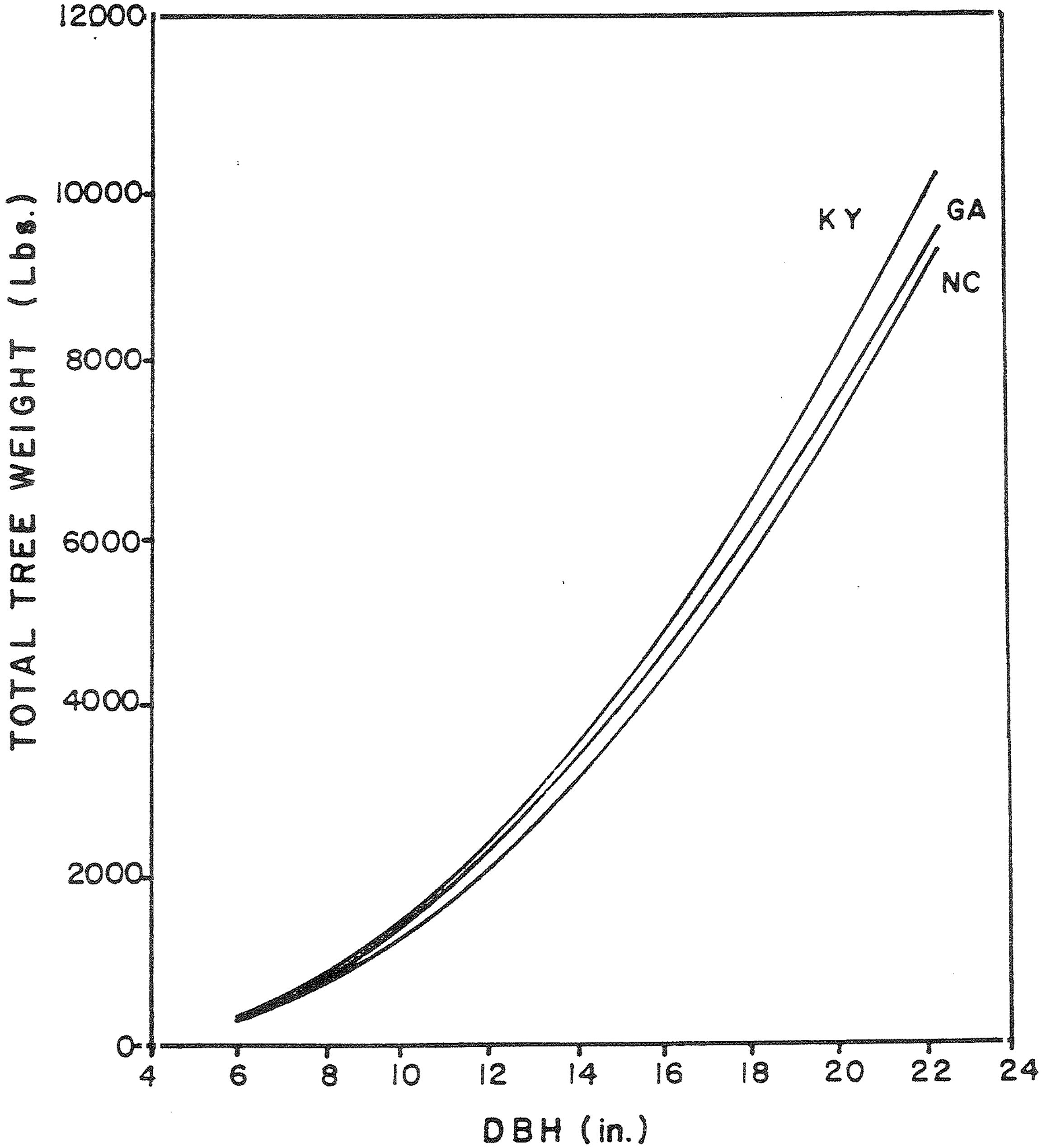

Figure 2. Predicted white oak total tree weight when equations, based on d.b.h. and total height for locations with different total height to d.b.h. ratios are applied to the same trees.

Table 4. Linear association of total tree and tree component weight with d.b.h. and various tree heights for southern species groups.

Tree dimensions	Tree component weight[1/]			
	Total tree	Saw-log stem	Stem 4-inch top	Crown
	-------- Correlation coefficient (r) ------------			
		Hard Hardwoods		
$(d.b.h.)^2$	.98	.90	.97	.92
$(d.b.h.)^2$ x (TH)	.99	.95	.99	.91
$(d.b.h.)^2$ x (H4)	.98	.95	.99	.90
$(d.b.h.)^2$ x (MH)	.90	.98	.94	.72
		Soft Hardwoods		
$(d.b.h.)^2$	.98	.94	.98	.77
$(d.b.h.)^2$ x (TH)	.97	.97	.98	.70
$(d.b.h.)^2$ x (H4)	.97	.97	.98	.68
$(d.b.h.)^2$ x (MH)	.90	.97	.95	.40
		Pine		
$(d.b.h.)^2$	.97	.96	.97	.85
$(d.b.h.)^2$ x (TH)	.97	.98	.98	.80
$(d.b.h.)^2$ x (H4)	.97	.98	.98	.80
$(d.b.h.)^2$ x (MH)	.95	.98	.96	.76

[1/]Weight of wood and bark.

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